Gravity-Driven Collapse of Explosively Damaged Rock

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SRI International (formerly Stanford Research Institute) is a non-profit research institute performing contract research for the U. S. government, commercial industry, and foreign governments. The Poulter Laboratory for Applied Mechanics specializes in studies of the response of materials and structures to severe mechanical environments. Much of Poulter Laboratory's experience and expertise is in the area of small-scale explosive and impact testing. A few recent publications of potential interest to centrifuge modelers are listed below. More about SRI and Poulter Lab (including information about our explosive test site) can be found at our web page: http://www.sri.com/psd/applied/index.html

•Groethe, M. A. and J. K. Gran, "Ground-Shock Enhancement using Multiple Explosive Charges," 16th International Symposium on Military Aspects of Blast and Shock, Oxford, England, UK, 10-15 September 2000.

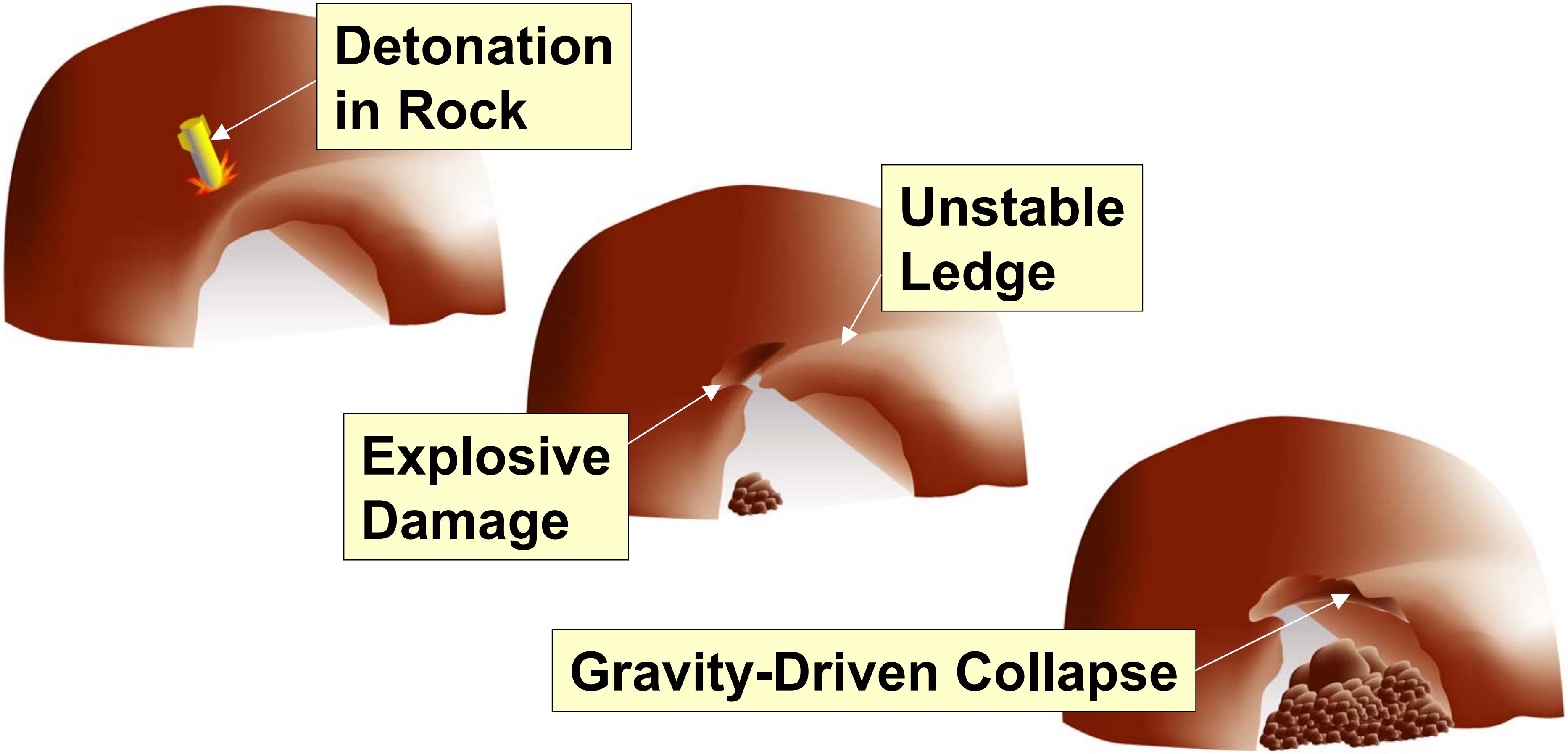
•Gran, J. K., C. M. Romander, D. Chitty, and R. Lausund, "A Laboratory Investigation of Underground Excavation in Monolithic and Jointed Rock by Explosive Charges," 16th International Symposium on Military Aspects of Blast and Shock, Oxford, England, UK, 10-15 September 2000.

•Gran, J. K., P. Gefken, R. Guirguis, and H. Sandusky, "Underwater Interface Pressure Measurements with Ytterbium Flatpack Stress Gauges," 69th Shock and Vibration Symposium, Minneapolis, MN, 12-16 October 1998.

•Gran, J. K. and P. E. Senseny, "Compression Bending of Scale Model Reinforced Concrete Walls," ASCE Journal of Engineering Mechanics, Vol. 122, No. 7, pp. 660-668, July 1996.

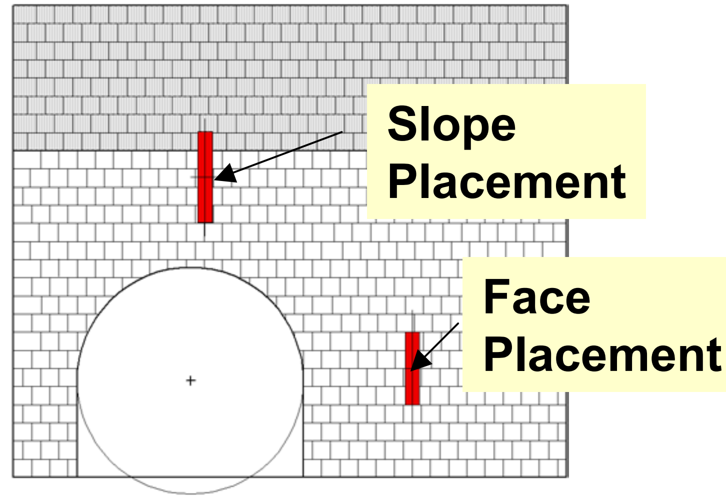
•Gran, J. K., J. R. Bruce, and J. D. Colton, "Scale Modeling of Buried Reinforced Concrete Structures under Air Blast Loading," ACI Publication SP 73-7, *Dynamic Modeling of Concrete Structures,* H. G. Harris, ed., 1982.

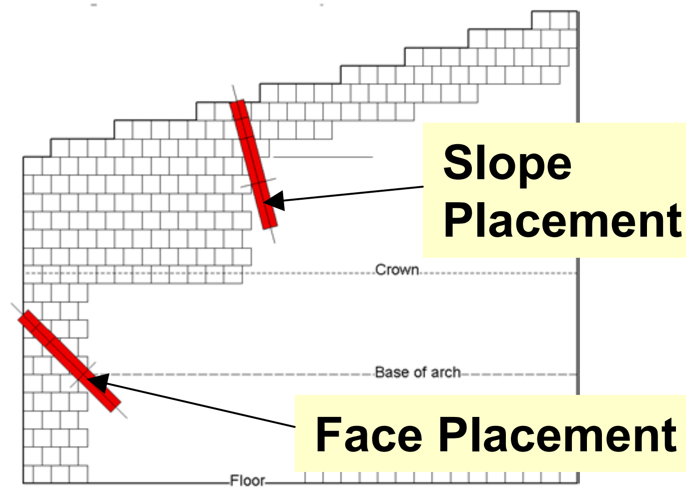
Gravity-Driven Collapse of Explosively Damaged Rock



The experiments presented here investigated the potential of producing enhanced rock fall at a tunnel entrance by destabilizing the rock cover with an explosive detonation. Our approach was twofold: a) to test whether scaled gravity is necessary to trigger the fall of destabilized rock or that 1-g testing would produce the same result, and b) to determine whether the explosive damage and destabilized rock fall occur at very different times and stress levels, offering the potential to study these aspects of the problems separately, that is, with 1-g explosive tests to produce damage followed by scaled gravity to trigger the destabilized rock fall.

Small-Scale Jointed Rock Collapse Tests in the ERDC/WES Centrifuge





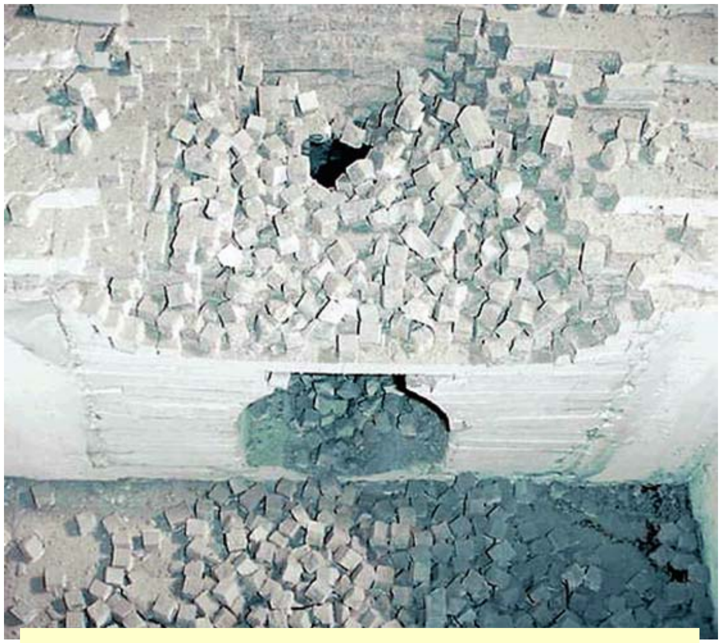
The material of the physical models was manufactured jointed rock with equal layer thickness and joint spacing. The manufacturing process was to grind flat the top and bottom surfaces of the plates and then crack each plate into rough cubes by pressing between knife-edge bars on an orthogonal grid. Because the plates were edge-wrapped with fiberglass tape during the cracking process, they never fell into pieces and the joints were in intimate contact at the end of the process. These plates were then stacked, encased in a cement-based grout, and the tunnel was bored into the model with a core drill.

Note that this manufactured jointed rock is anisotropic because the horizontal surfaces (between layers) are smooth ground surfaces whereas the vertical surfaces (joints) have the roughness of fractures.

Four models were built and two explosive charge placements were tested. For both placements a model was tested with the detonation at 1 g after which that model was accelerated to 50 g. The other model was tested with the detonation at 50 g.

Each model was tested with only one explosive charge. The two charge placements are shown in one drawing for compactness.

Rubble from Slope-Placed Detonations



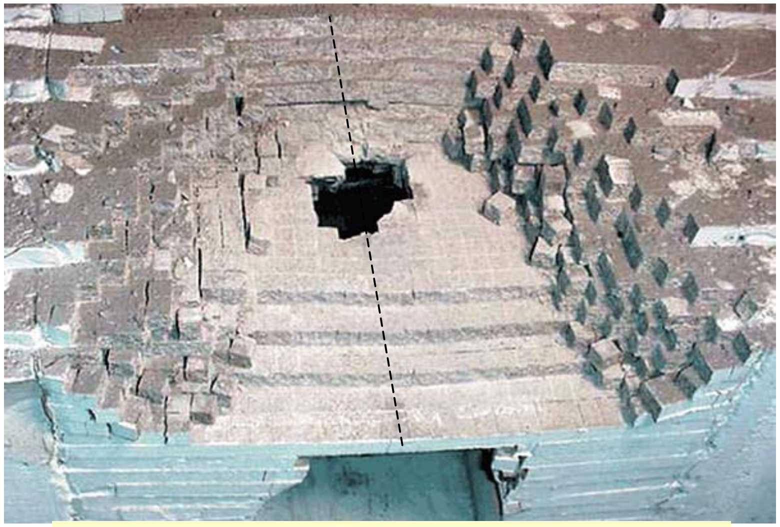
1-g Detonation, 50-g Gravity

50-g Detonation, 50-g Gravity

The surface craters and internal craters produced by the slope-placed detonations were quantitatively quite similar based on volumes of the rubble in the tunnel and on the apron in front of the entrance. Qualitatively, the model with the 50-g detonation appears to provide a more accurate illustration of the flow pattern of the rock especially toward the vertical front face. The most significant quantitative difference is the greater removal of rock immediately above the tunnel entrance.

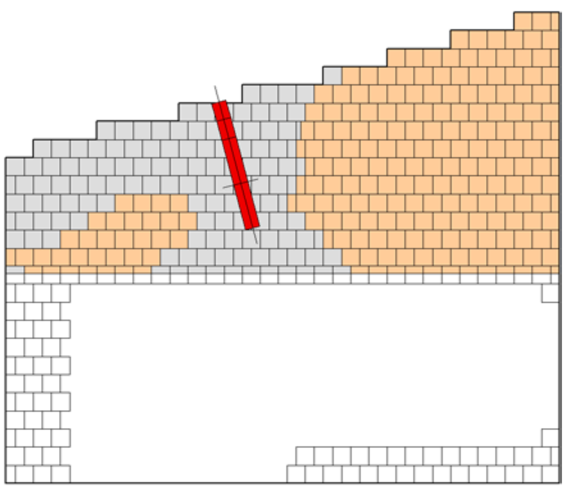
When the model with the 1-g detonation was accelerated to 50 g, only a few blocks of rock fell into the hole in the center of the crater--no additional rock fall occurred at the tunnel entrance.

"True" Craters from Slope-Placed Detonations

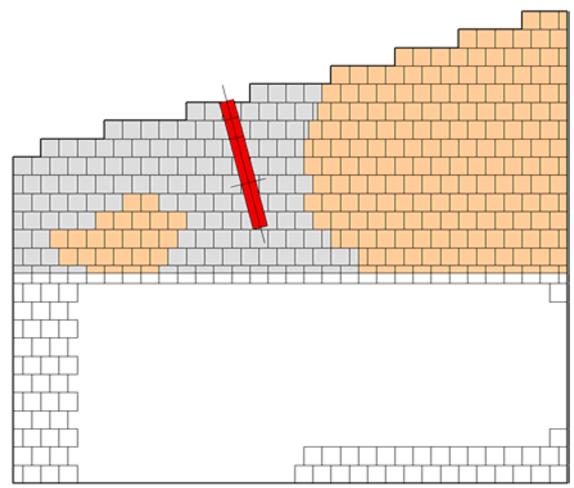


1-g Detonation, 50-g Gravity

50-g Detonation, 50-g Gravity

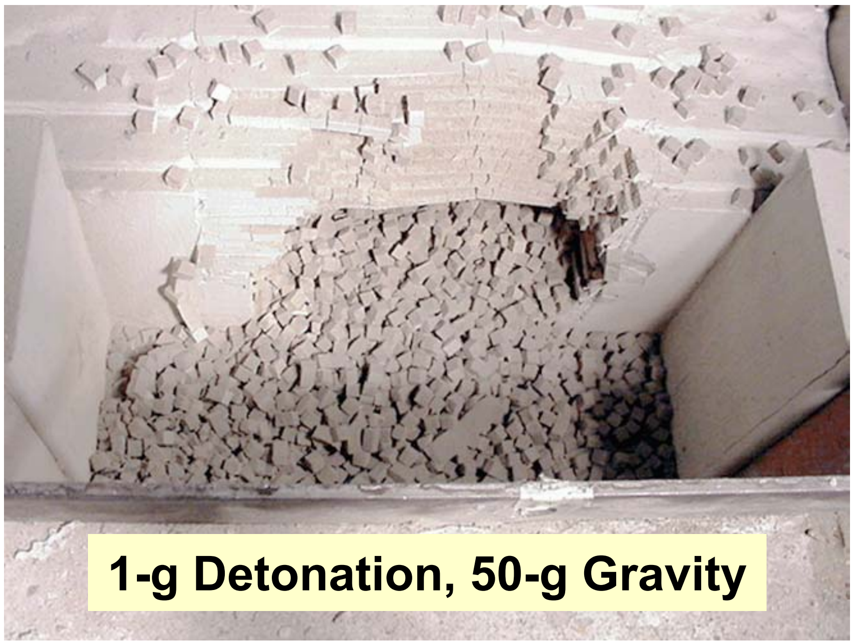


Section Profiles



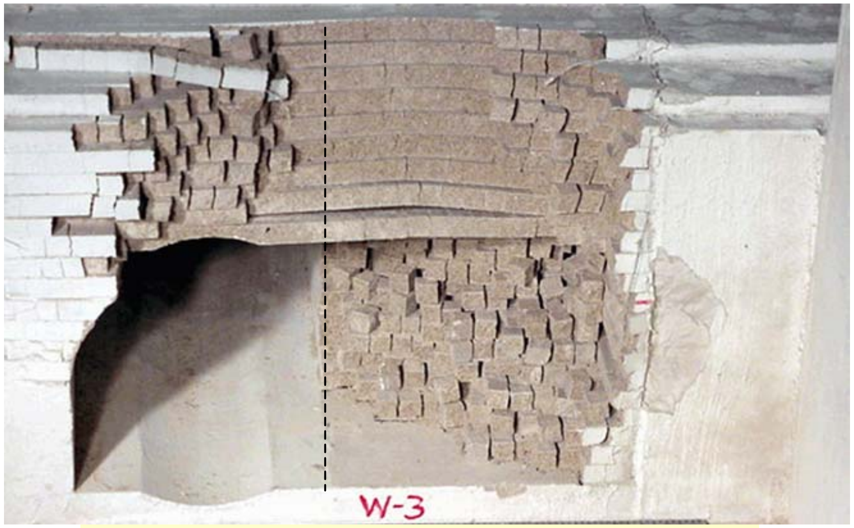
The rubble in the craters was removed by hand to expose the true craters--those produced by the explosive detonation but without ejecta falling or sliding back in. Again near the back of the craters the two models are nearly identical but there is a clear difference in the manner and amount of block motion off the front edge and over the tunnel entrance. We postulate that this motion was affected by gravity through the friction between the ground surfaces separating the rock layers. That is, in the 1-g test the horizontal rock motion was less resisted by shear stresses between layers.

Rubble from Face-Placed Detonations

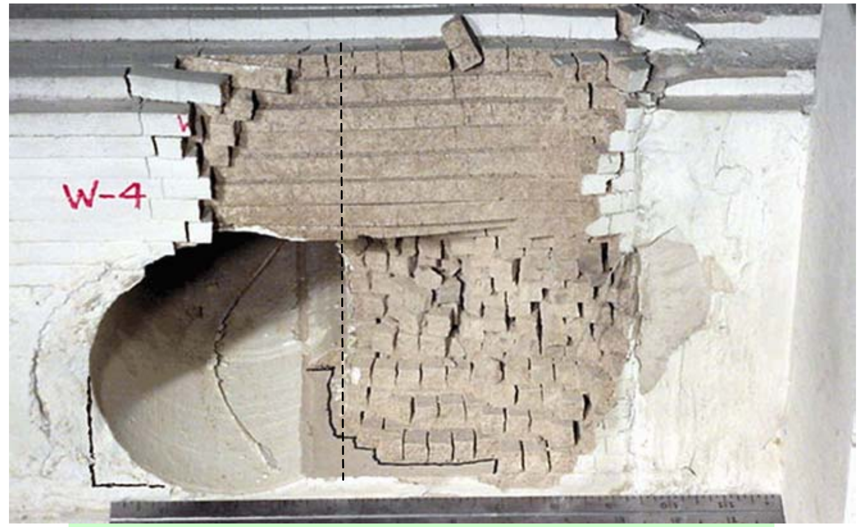


For the face-placed detonations the cratering was primarily horizontal heaving into the tunnel from the side, with some additional shallow scabbing of the front face above the tunnel. The volume of rock heaved into the tunnel and onto the apron was much greater in the 1-g test; again essentially no additional rock fall occurred in the 1-g model when it was accelerated to 50 g.

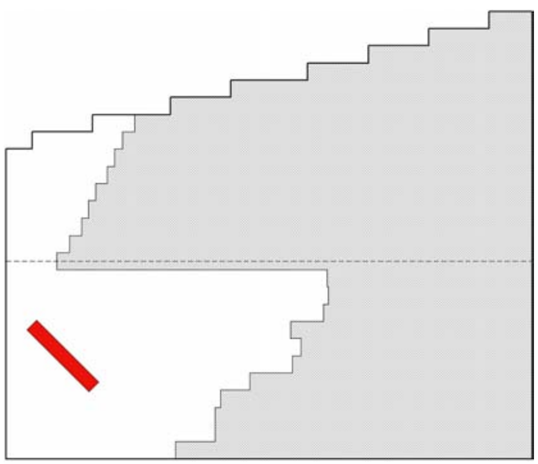
Craters from Face-Placed Detonations



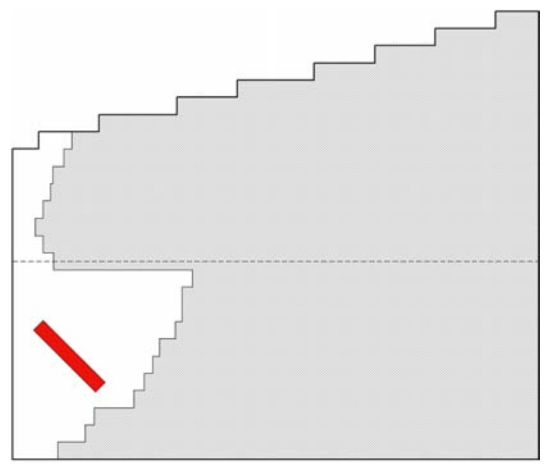
1-g Detonation, 50-g Gravity



50-g Detonation, 50-g Gravity



Section Profiles



After cleanup, we can also more easily see the upward heave and joint opening in the plates above the detonation in the 1-g model. The lack of gravity again appears to have reduced the resistance to horizontal motion toward a free surface and allowed much more rock to be heaved into the tunnel. Whether the uplift of the layers also lessened the friction, we cannot say.

Conclusions

- **Gravity affects the strength of *this* manufactured jointed rock by increasing friction between layers.**
- **Gravity-enhanced strength reduces the damage produced by buried detonations, especially by limiting motion parallel to the layers and toward a free surface.**
- **Gravity-driven collapse was not produced in these tests but might be produced in a weaker (more highly jointed) rock or with different detonation locations.**
- **Gravity-driven collapse can and should be studied at small scale with centrifuge-supplied gravity.**

The primary finding in this study is that horizontal motion of the rock toward a free surface is dependent on gravity via the frictional stresses on the horizontal surfaces. However, this observation may be peculiar to *this* breed (or orientation) of jointed rock because those surfaces were probably unrealistically smooth.

Although the phenomenon of primary interest--gravity driven collapse of a destabilized rock mass--was not observed, it is arguable that other placements of explosive charges would create unstable overhangs that would subsequently fall under self-weight. Whether scaled gravity is needed to trigger the rock fall is also still not known, but it appears prudent to perform future tests in a centrifuge because of gravity's effect on the shear strength of the jointed rock.